HYDROLOGICAL REGIME OF THE AMUR RIVER AND CHANGES CAUSED BY ECONOMIC ACTIVITIES

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Regularities of origin and formation of run-off of big rivers are rather complex and are determined by many factors both of natural and technogenic origin. The Amur River is ranked the 10th by the length and drainage area among the world biggest rivers (Appolov, 1951, Hydrological studies, 1966, World…, 1974, Estimation…, 1989). Among the rivers in Russia it is the 3rd in length and the 4th in drainage area and water content after the Enisei, Ob and Lena rivers (Resources…, 1966, 1970).

Due to the intermediate geographical position between two areas of completely different physical and geographical conditions (humid Pacific coastal areas in the east and continental vast areas of East Siberia and Mongolia in the west) climatic conditions in the Amur Basin are rather diverse. Its climate is formed under the influence of both ocean and continental factors. That is why it varies from an extreme continental climate in the western part of the basin to a moderate continental climate with monsoon features in the eastern part of the basin (Resources…, 1966)

Also due to its geographical position the Amur Basin is affected with air masses of different origin, which are formed outside the basin and which cause different wind directions in different seasons of the years. Air flow changes result from interaction of air masses over the continent and the Pacific Ocean (Pacific Ocean…, 1966).

In winter a high pressure area over the continent (Asian anticyclone) interacts with a low pressure area over the north-western part of the Pacific Ocean (Aleut depression) and thus a continental climate in the basin is formed, characterized with low temperatures and air humidity.

When spring comes and air gets quickly warm, a pressure pattern over the basin gradually changes into its opposite and in summer the pressure is high over the ocean and is low over the continent and humid tropic masses penetrate from the ocean deep into the continent. These warm and humid air masses bring abundant, sometimes catastrophic rainfalls, which cause heavy floods with several peaks usually in the second half of summer and early autumn.

The Amur Basin is a large natural system, composed of numerous river basins, situated in different natural and climatic zones. Vastness of its drainage area, basin shape specifics, big tributaries located in different parts of the basin and precipitation characteristics (locality and usually high intensity) are the factors that divide the basin into several zones of peculiar run-off formation. The following zones are singled out (Fig.1) 1) Upper-Amur; 2) Zeya-Bureya; 3) Sungari and 4) Ussuri (Kim, 1989, 1999). Each run-off forming zone has a peculiar water regime, which differs from those of other zones. Multiyear fluctuations of water content in these zones do not coincide with each other. The share of each zone in Amur run-off formation is different and changes, depending of water content in the basin. At average a run-off forming share pattern is as follows: Argun and Shilka basin – 9.1 %; Zeya and Bureya basin – 27.2 %; Sungari basin – 27.6 %; Ussuri basin – 11.3 %. The total share of other numerous Amur tributaries is less 1/4 of the total run-off. Therefore the indicated zones are considered as determining the Amur run-off formation.

In various years Amur floods are formed in different zones. For instance, the 1957-year flood (35 500 m^3/sec) was formed in the basins of the Sungari (48 %) and the Zeya and the Bureya (42 %). The main source of the 1911-year flood (35 000 m^3/sec) was the Sungari, which share in the flood was 65 %. The 1958-year flood (30 100 m^3/sec) was formed in the basins of the Zeya and the Bureya (62 %) and the Argun and the Shilka (19 %).

Each of the described zones can cause heavy floods on the Amur River. Moreover, the time, when flood waves pass certain zones, is very important. Most disastrous floods on the Amur were observed in those years, when foods, even small, occur in several run-off forming zones at the same time (Kim, 1999).

Besides these main flood-forming zones, there are areas, relatively small in size, where increased precipitation is observed comparing to the near-by territories (Tungussky, Khorsky). In these areas local floods are often formed, which are usually sudden and characterized with a rapid rise of water level. (Kim, Makhinov, 1991).

The Amur River belongs to the Far Eastern river type, characterized with a marked prevalence of rainfall run-off in the total annual run-off. The share of rainfall run-off is 50-70 % at average, whereas snow surface run-off is 10-20% and subsurface drainage is 10 – 30 % (Resources..., 1966, Mordovin, 1996, Kim, Shamov, 2000).

The Amur River in its middle and lower reaches is characterized with a specific flood regime, described with relatively moderate run-off in time of spring floods compared to summer and autumn floods, which in some years become catastrophic and cause much damage and many losses. Summer rains are the main source of water content in the river. That is why, 89 – 96 % of river run-off is formed in the warm period of the year (from April to October). At the end of April – beginning of May a spring flood is formed with melting snow water. The flood wave is the highest usually in the second half of May due to often rains and intensive snow melting in the mountains. Spring floods make only 10-12 % of annual river run-off.

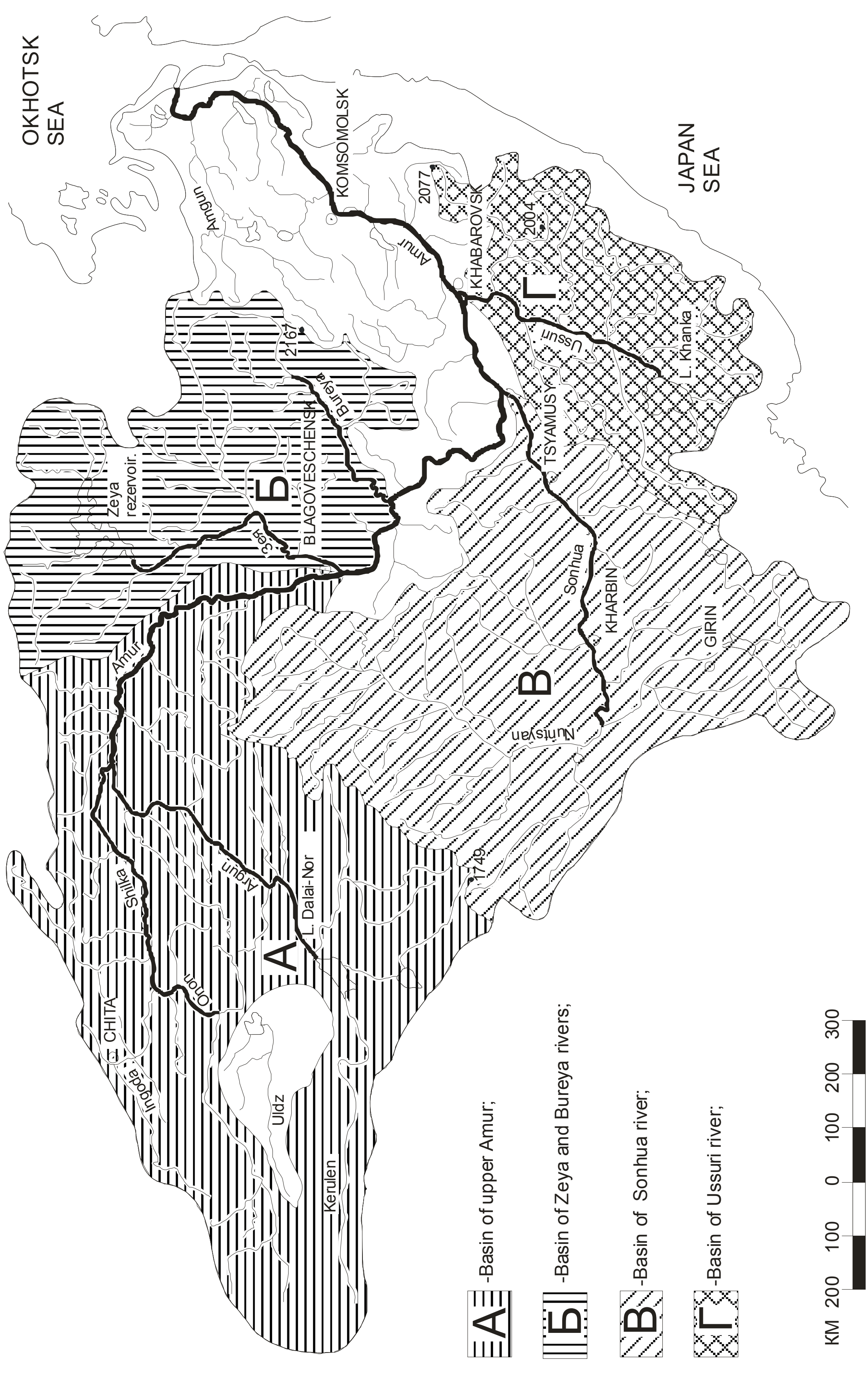

Fig. 1. Scheme of the Main Zone of Amur Run-off Formation

In the warm time of the years the Amur has 3-4 rainfall floods with peaks that exceed before-flood low water level by 5-8 meters. The amplitude of Amur run-off fluctuations at the Maly Khingan Mountain Range is within the wide range of 12 meters and in the estuary it is within the range of 1.5 meters (Kim, Makhinov, 1991).

The Amur freezes in the middle of November and clears from ice at the end of April – beginning of May. In autumn ice flow is comparatively gentle, but in spring there are lots of ice jams and water level rapidly rises. The thickest ice cover is observed in March.

The process of smallest water discharge formation in very complicated as minimal run-off depends on many factors, which noticeably change both in space and time. Two periods of minimal river run-off are usually observed: one in the ice-free period and the other in winter. Amur low water in summer is often not much evident and may be observed in June or July. Summer low water period is not long. In some low water content year-periods, e.g. in 1997-2008, summer low water was well-marked. Extremely low water levels were observed at the end of June – beginning of July in 2000, 2001, 2003, 2007 and 2008.

After river freezing, usually in time of moderate water discharge, Amur discharge rapidly decreases and in March reaches its minimum (e.g.153 m^3/sec in March 1922 at Khabarovsk observation station). After the water reservoir of the Zeya hydropower station was put into operation minimal winter water discharge significantly increased.

The Amur is characterized with a very complicated mechanism of flood wave spreading. We studied some specifics of flood wave behavior in the Lower-Amur based on observations of rather heavy floods, which happened in 1959, 1981 and 1984. The Amur valley has specific interchange of narrowings and widenings. That is why the flooding regime noticeable varies along the valley.

The Amur flood-plain is very wide (25-30 км) within large plains (Low-Amur, Udyl-Kisin, Lower-Amur). In the mountain parts of the Amur valley the flood-plain consists of fragments either in the form of narrow strips along the river banks as or in the form of small but very elongated islands. The interchange of flood-plain narrowings and widenings makes flood wave behavior very complicated. Besides, in areas of valley widening the Amur stream is split into lots of channels of different size and configuration. This factor also affects flood wave behavior.

Flood wave spreading dynamics in the lower Amur reaches between the Maly Khingan and the Amur estuary is clearly seen in Fig. 2. The wave peak sharply decreases here, e.g. from 11.97 to 1.47 m (1959); from 5.75 to 1.52 m (1981), from 11.75 to 1.23 m (1984). However, flood wave peaks subside in different parts of the valley differently. Before a flood-plain widening and within a widening a flood wave is smoothed and before a narrowing it raises, e.g. the following wave increase data were registered at hydrological observation stations: at Pompeevka by 0.23 m (1959) and 0.51 m (1981); at Komsomolsk-on-Amur by 1.36 m (1959), 2.40 m (1981) and 2.06 m (1984).

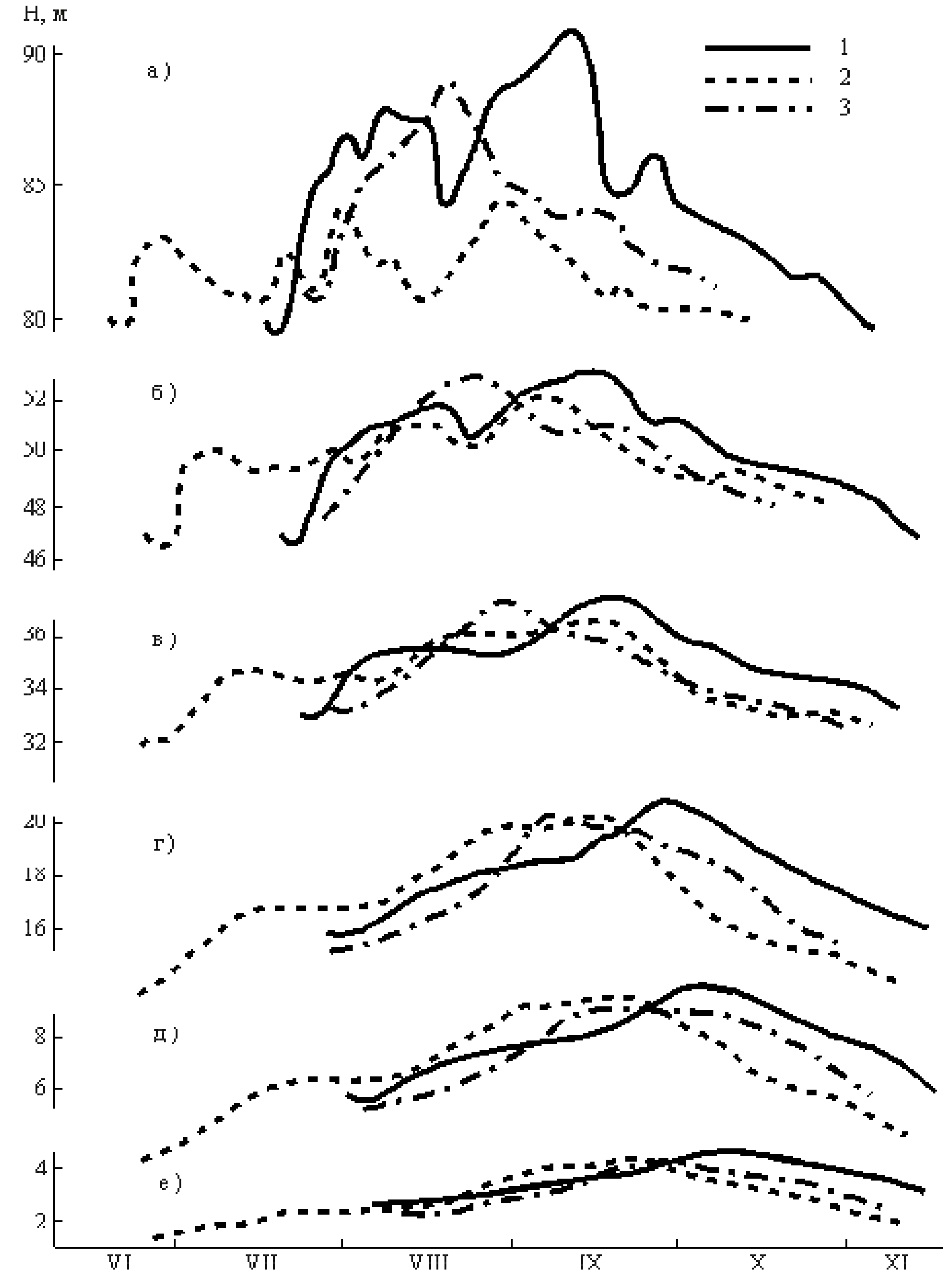

Fig. 2. Transformation of a Flood Wave in the Middle- and Lower Amur Valley in 1959 (1), 1981 (2) and 1984 (3).

а – Pashkovo village (1533 km from the estuary), б – Leniskoe village (1190 km from the estuary), в – Khabarovsk City (966 km from the estuary), г – Komsomolsk-on-Amur City (614 km from the estuary), д – Mariinskoe village (326 km from the estuary), е – Takhta village (48 km from the estuary).

The flood wave passing speed also changes. Before narrowings it is 30-40 km/day, in narrowing it reaches 100 km/day and in widenings it subsides to 40-50 km/day. Such flood wave behavior is explained with the fact that before a narrowing the wave height increases and its passing speed decreases. In the narrowing a water discharge capacity of the river-bed decreases. That is why, before the narrowing the wave height increases, but its passing speed decreases. In the narrowing itself water is discharged through the main stream, and due to a higher incline of water surface the flood passing speed increases. In widenings the main stream is split into numerous big channels, thus increasing discharge capacity and making the flood wave height and passing speed decrease. In the Lower-Amur plain, which is flooded even with a minor water rise, a flood wave becomes smoother.

Thus, the Amur valley structure specifics, i.e. its interchanging narrowings and widenings significantly affect the flood wave spreading. Water level fluctuations and flood peak passing speeds are different at different parts of the valley, thus causing varied flooding of the valley and its ecological diversity.

It is known that big river surroundings are highly populated and rivers suffer great anthropogenic impact. At present 100 million people live in the Amur Basin (mostly in China). Near big cities the Amur has many economic problems. Various hydrotechnical constructions (hydropower station reservoirs and dams, bank reinforcements, etc.), river-bed and bottom changes and construction material excavation from the river bottom significantly affect river water regime and dynamics of river-bed processes (Kalinin, 1968; Ermolina, Kalinin, 1975; Klige, 1982; Ljvovich, 1982, 1986). Most evident the changes are at river junctures due to the redistribution of water flow. The results are widening of some water channels and blocking the others. This often causes difficulties in operations of ports, water inlets and other economically important objects in the river-bed and at its banks.

The Amur River is a transboundary river, which basin is shared by the Russian Federation (1 002 thousand km^2), the Peoples' Republic of China (820 thousand km^2), the Mongolian Peoples' Republic (32 thousand km^2) and Korean Peoples' Democratic Republic (less than 5 km^2 of the Lake Chkhondzi coast line in Sungari River head) (Resurces…, 1966, 1970). Economic activities in all Amur-bordering countries significantly affect Amur water quality, run-off formation and flood behavior.

In the Lower-Amur valley the river-bed suffers the heaviest anthropogenic impact, especially near the cities of Khabarovsk and Komsomolsk-on-Amur. Here big bridges across the Amur are constructed and big water supply inlets are operating. A polder is constructed on the Bolshoi Ussuriisky Island near Khabarovsk. A similar polder is under construction on the Shirokhonda Island near Konsomolsk-on-Amur. By now a complex of hydrotechnical contractions has been completed on the Pensenskaya and Beshenaya sub-channels and a significant part of the Amur waters has been returned to its main stream.

There are two water reservoirs of the Zeya and Bureya hydropower stations under operation in the Russian part of the Amur Basin. The Zeya hydropower station was put into operation in 1975. Due to its operation the Amur water regime has changes. Before the dam was put into operation the Zeya discharge in winter low water was about 50 m^3/sec, whereas after the reservoir completion it increased 20-25 times. Annual average discharge reached 800 – 1000 m^3/sec, and in winter reached 1200 m^3/sec.

Fig. 3 presents data on water level fluctuations in the Zeya River before (1971) and after (1985) the Zeya hydropower station was put into operation. Natural water content was approximately the same in these years. When the water regime was not regulated the amplitude of water level fluctuations did not exceed 5 meters and main river run-off was in the non-freezing period, whereas winter run-off was only 5 %.

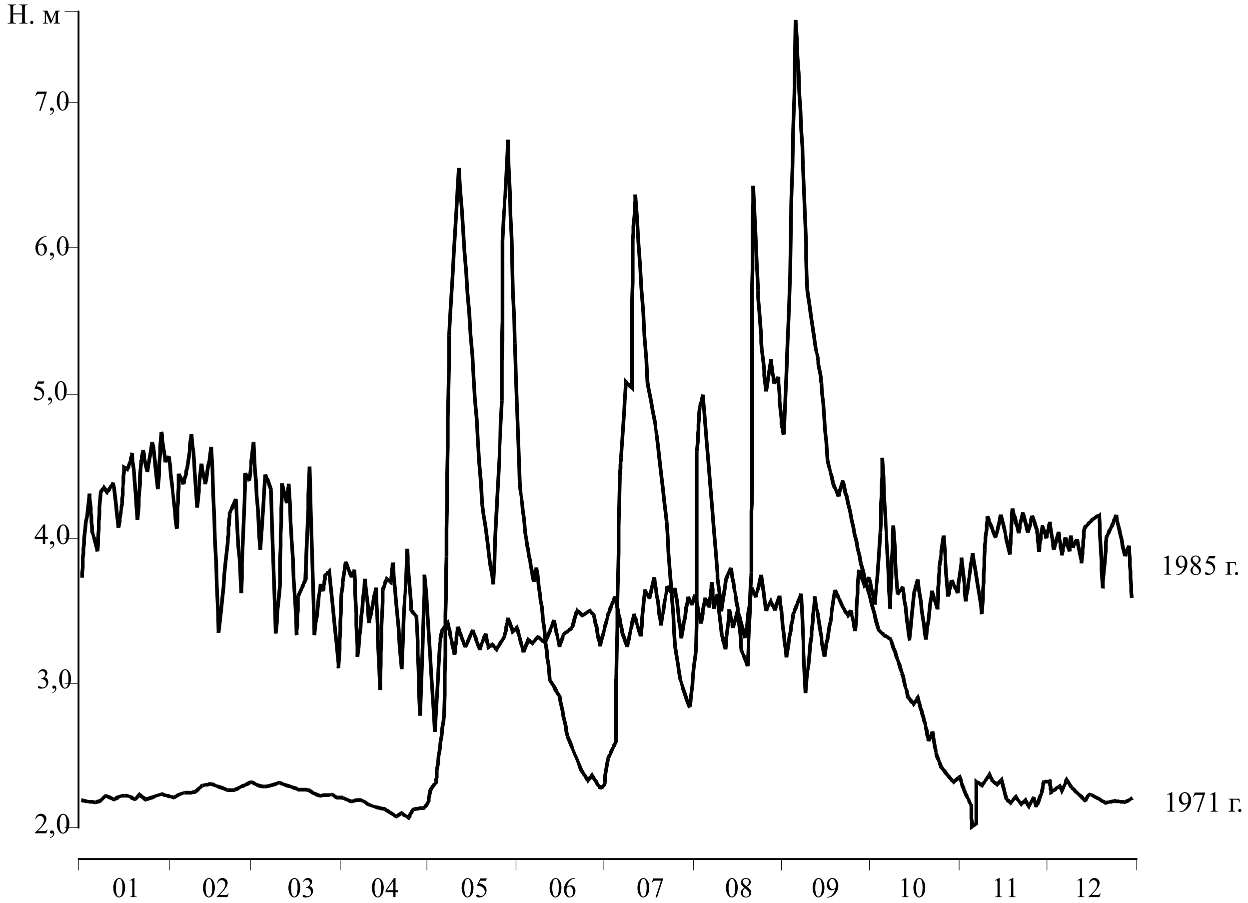

Fig. 3. Chart of Water Level Fluctuations in the Zeya River (Zarechnaya Sloboda St.) Before and After the Construction of the Zeya Hydropower Station

After the Zeya basin has been regulated the amplitude of water level fluctuations decreased to 1.5-2.0 meters. At resent absolute values of winter discharge exceed summer discharge values. Amur discharge has been redistributed within a year and the Amur water regime up to its estuary has changed significantly.

After the Zeya hydropower station was put into operation the annual average amplitude of water level fluctuations has decreased from 1.75 meters down the river and at Khabarovsk is now 0.98 m, at Bogorodskoe is 0.63 m and at Nickolaevsk-on-Amur it is nearly smoothed. Maximal drops of the water level fluctuation amplitude are registered in the area of the Maly Khingan mountain range (e.g. 1.77 m at Pashkovo village and 2.25 at Pompeevka village)

The decrease of the highest water levels (0.86 m at Blagoveshchensk, 0.60 m at Khabarovsk and 0.47 m at Bogorodskoe) is also observed (Fig 4).

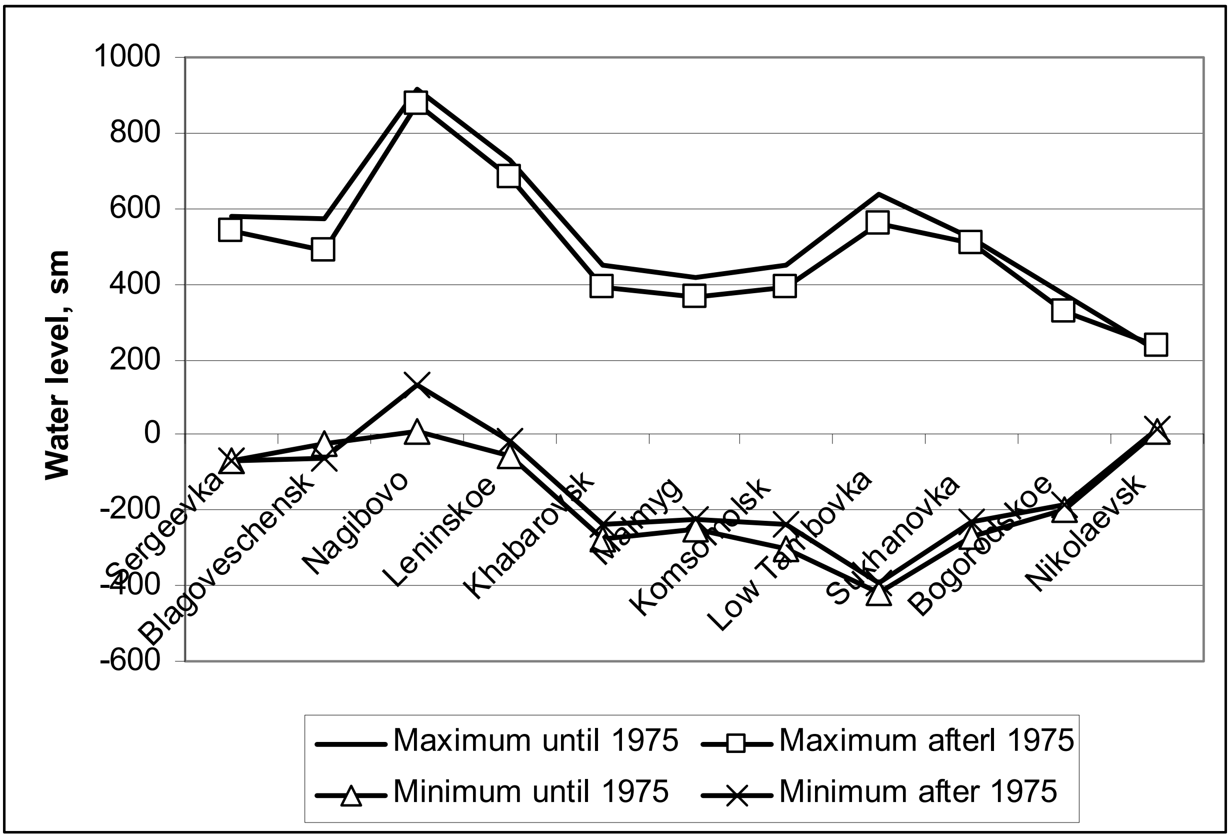

Fig. 4. Intergrated Chart of Typical Water Level Fluctuations in the Amur River Before and After the Zeya Hydropower Station Was Put into Operation.

Mean minimal water levels in winter are found to increase. In the Middle-Amur they usually fluctuate in the range 0.5-1.0 m with exception of the Maly Khingan, where they reach 1.24 m. In the Amur lower reaches winter water levels did not increase much, by 0.11 m in particular.

Values of the increase of mean minimal water levels in the Amur in the non-freezing period nearly coincide with those observed in winter. Although the area, regulated by the Zeya hydropower facility, is only 4.5% of the Amur Basin, its impact on the Amur run-off is noticeable, especially in the period of winter low water in the river passage from Khabarovsk to Bogorodskoe. In the Amur pre-estuary passage the Zeya hydropower facility impact on the Amur regime is hardly noticeable (Kim, 1999).

However, Zeya run-off regulation caused significant changes of the Amur run-off, especially in winter. As the result in winter minimal water levels are stably increasing and water discharge is increasing even several times. This increase of Amur water content certainly has a positive effect as concentrations of dissolved and suspended pollutants significantly decrease.

Since 2003, when the Bureya hydropower station reservoir was put into operation, the Amur water regime has again noticeably changed. At present 92 % of the Bureya River run-off (3.5% of the Amur run-off) is regulated by the Bureya hydropower station.

New prospects of hydropower constructions in the Upper-Amur are being discussed.

In the basin of the Sungari, the biggest Amur tributary, a complex of hydrotechnical facilities, including several water reservoirs (Fynman, Paishan, etc.) has been constructed (North-East China, 1989; Ganzei, 2004). New constructions of hydropower facilities and water reservoir coupled with the existing ones may cause significant transformations of the Amur hydrological regime.

Sand and gravel extractions from the river bottom do not produce a noticeable effect on water ecosystems. As suspended matter accumulation is rather intensive river-bed damages are restored in 2-3 years.

Studies of sand and gravel excavations in the Lower-Amur showed that suspended matter plays a key role in water quality formation and is a key factor of water turbidity. Some river-bed excavations cause local river-bed transformations, bank washing out and sediment accumulations in the form of islands.

The accurate assessment of the economic impact on the Amur hydrological regime will not only foster rational natural resource use in the basin, but also speed up the development of measures that will lessen the anthropogenic load on the Amur River ecosystem and its adjacent territories.

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